

THE EFFECTS OF WHOLE-BODY EXERCISE ON  
TWO-STAGE CHOICE REACTION TIME TASK PERFORMANCE

A THESIS

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TWO-STAGE CHOICE REACTION TIME TASK PERFORMANCE

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## SUMMARY

Whole-body exercise on the bicycle ergometer at four loads (30, 60, 120, 180 watts) and four rates (30, 40, 60, 90 rpm) was investigated. A two-stage choice reaction time task was used to detect changes in psychomotor performance as measured by choice reaction time and number of errors prior to, during and after exercise. Four male subjects, ages 21-34, were tested.

The mechanical and physiological variables were parameterized so as to detect the effects of the following on two-stage choice reaction time:

1. Level of mechanical work load (30, 60, 120, 180 watts)  
Rate (30, 40, 60, 90 rpm)
2. Level of physiological exertion  
Oxygen consumption  
Heart rate
3. Duration of exercise
4. Subject of differences.

The two-stage choice reaction time task consisted of a display having four vertical lights and a window presenting a four digit number (1111 to 4444). The subject had to detect which of the four lights was lit, read the corresponding numerical digit in the display window, and press the correct button on a four button hand control.

The data indicated a very significant load effect and

choice reaction time was observed to decrease with increasing rate of mechanical work. No relation of practical significance was detected between the physiological parameters (oxygen consumption and heart rate) and choice reaction time performance.

A very significant period effect was detected, in that choice reaction time was seen to increase at the start of exercise, however, in the second and third thirds of the exercise period, choice reaction time significantly improved. Moreover, in the last third of the exercise and in the recovery period, choice reaction time was significantly lower than the mean.

The study indicates that mechanical work significantly effects choice reaction time performance. It also indicates that significant improvements in performance can be expected after subjects have adjusted to the work stress presented and during recovery.

## CHAPTER I

### INTRODUCTION

#### Statement of Problem

Although physiological studies have allowed scientists to make reliable estimates of individual response to the demands of work situations, very little information exists which can be transformed into predictive statements about how those demands will effect an individual's task performance. If such predictive statements can be made, then opportunities exist for the design of work activities in a manner conducive to high performance.

This study investigates two-stage choice reaction time task performance during whole-body exercise on a bi-cycle ergometer. The study attempts to quantify the effects of the following on two-stage choice reaction time (TSCRT) performance:

1. Level of mechanical work
  - Load in watts
  - Rate in revolutions per minute
2. Level of physiological exertion
  - Oxygen consumption
  - Heart rate
3. Duration of exercise
4. Subject differences

Choice reaction time and number of errors were used to

measure TSCRT task performance.

### Objective

The objective of this study is to investigate the degree to which each of the following variables effects TSCRT.

1. Physical Work Load - Does the amount of mechanical work measured in watts effect TSCRT task performance? In particular, are there work loads at which TSCRT shows increases or decreases? Equally important, does performance vary with the rate of pedaling on the bicycle ergometer?
2. Physiological Load - Is there a significant relation between oxygen consumption rate and/or heart rate and TSCRT task performance?
3. Duration of Work - Does the duration of the work period effect performance, and is there a significant difference between pre-test performance, and performance during thirds of the exercise period? Is there a recovery effect?
4. Subject Differences - Are there practical differences in learning or exercise performance between subjects?

### Scope

This study involves whole-body exercise on the bicycle ergometer at four loads (30, 40, 120, and 180 watts) and



rates (30, 40, 60, and 90 rpm). The exercise load-rate combinations considered would be classified as light to moderate work on the rating scale of Wells (19). A two-stage choice reaction time task was used to detect changes in psychomotor performance as measured by choice reaction time and number of errors prior to, during, and after exercise. Four male subjects, ages 21-34 were tested.



## CHAPTER II

### LITERATURE REVIEW

Previous studies relating reaction time, movement time, and the performance of skilled tasks to energy expenditure are presented in this chapter. In particular, section one contains studies investigating simple reaction time and movement time. Section two presents studies in which tasks requiring a higher level of subject skill are discussed. Section three briefly reviews literature on vehicle driving studies requiring simultaneous performance of primary and secondary psychomotor tasks.

#### The Effects of Exercise on Simple Reaction Time

Sorge (18) tested subjects of three fitness levels using a modified Harvard step-test at two intensity levels - 35 and 40 steps per minute for five minutes. A significant post-exercise increase in speed of reaction was detected. Elbel (7) had subjects perform alternate periods of stool stepping and push-ups. Three periods of stepping at 30 steps per minute for two to four minutes were required. Interspaced with these bouts the subjects were requested to perform as many push-ups as possible. Even the maximum amount of work performed in this manner had no effect on reaction time performance after exercise; however, it was observed that

subjects who participated in periods of athletic competition (basketball) exhibited a significantly shortened reaction time.

Pierson and Rich (14) studied performance of a simple reaction-movement time task. Upon presentation of a neon light stimulus, the subject released a switch and extended his hand through a light beam. Each subject was tested until the experimenter noted signs of obvious physical distress - an average of 49 minutes. Oxygen consumption measures indicated an energy expenditure rate of 86.8 kcal/hour. Performance remained constant except for a brief, randomly distributed period of performance decrement in each subject's test. Sembrowich (17) found that two minute bouts on the bicycle ergometer at 200 watts - 60 rpm and 300 watts - 90 rpm with various work rest cycles, had no significant effect on simple reaction time or movement time. Meyers, et al, (13) used stool stepping at a rate of 30 steps per minute for five minutes. No significant post-exercise effect of such exercise on simple foot and finger reaction time was detected.

Carron (2) had subjects crank a hand ergometer at a load of 34 watts for five minutes or until exhaustion. In studying the time related effects of interpolated exercise on the learning of a pursuit rotor task, it was found that the exercise had a significant effect on the amount of performance improvement exhibited by subjects during individual

test periods; however, no significant difference in the total amount learned by exercised and non-exercised subjects over the whole experiment was detected.

#### The Effects of Exercise on Skilled Task Performance

Hammerton and Tickner (10) applied a 400 second burst of stool-stepping at the rate of 60 steps per minute on a 12 inch high block to normally fit and very fit members of the British Royal Navy. The performance on a target acquisition task with first order control function remained unchanged after this violent exercise, regardless of level of fitness. On a similar task with second order control function, exercise was found to have a significant effect on normally fit subjects only. They concluded that "tasks of moderate level of difficulty can be carried out by moderately fit men even after violent exercise." A later study by Hammerton (9) using similar subjects and exercise conditions showed that bursts of violent activity did not significantly effect the performance of a simple cognitive task (sentence comprehension).

Evans (8) studied the effects of treadmill work on pistol firing. Subjects were instructed to walk at their maximum speed on a treadmill. Decrements on the exercise task of 0%, 10%, 20%, and 30% were considered reached when the subject slowed to the above percentages of his maximum walking speed. A group of six pistol shots was performed at



each exercise decrement level with the subject stepping off the treadmill to fire. The exercise was found to cause a significant increase in subjects' time to acquire target (time to first shoot after ceasing exercise) and time to fire the remaining five shots.

### Fatigue Effects in Vehicle Driving

A secondary set of studies which can provide additional insight into skilled psychomotor performance deals with automotive driving. These studies generally involve a secondary psychomotor task imposed upon a primary psychomotor task. They are of particular interest since the primary motor task is continuous.

Ryan and Warner (16) studied the effects of long term driving as indicated by several psychological variables. It was found that after periods of 8.5 hours of standard driving, there was a significant decrease in performance of color naming, both in time to complete the test and number of errors made, and a decrease in speed of completion of mental addition tasks. Improvements of performance on the above tasks were reported when light work was substituted for driving. They concluded "the research indicates that the effects of long hours of automobile driving is a loss of efficiency of human reactions."

Herbert and Jaynes (11) used a battery of tests of high face validity to evaluate driving performance. Subjects who

underwent zero hours of fatigue driving had the highest overall score on the tests. There was a variable, but continuous decrement in performance demonstrated by groups performing increased hours of fatigue driving up to seven hours.

In addition to these studies, Jones, Flinn and Hammond (12) reported consistent performance decrements and Dobbins, Tiedeman and Skordahl (6) reported no performance change on various tests imposed during and after vehicle driving.

#### Summary of Findings

While Astrand and Rodahl (1), Ricci (15), Wells (19), and many other investigators have sought to measure the physiological costs of various forms of activity, there has been a surprising lack of research concerning the effects of physical activity on the performance of skilled tasks. Studies of the effects of physical activity on reaction time have been inconclusive in their findings. Those few studies which directly relate performance of skilled tasks and energy expenditure concentrate on physical activity at levels generally encountered in emergency or other rare situations, rather than energy expenditure rates common to the usual class of industrial and military tasks. Moreover, it is important to note that in the studies discussed above, the skilled tasks were always performed before and after, but not during, exercise. The situation which is more often

encountered in actual work situations - simultaneous physical activity and psychomotor performance - has not been considered. Vehicle driving research, while it does offer a study of continuous and simultaneous performance of psychomotor tasks, is more concerned with information processing load and fatigue effects. Further, since the primary task presents such a light physiological load, little can be inferred about the effects of physical activity on performance.

## CHAPTER III

### METHODS AND PROCEDURES

This chapter presents a description of the equipment and instrumentation used in this study. This is followed by a description of the experimental and statistical procedures employed.

#### Instrumentation

##### Two-Stage Choice Reaction Time (TSCRT) Task

The device used was designed and developed by Dr. R. M. Chambers and Dr. R. Kineman, Captain, MC, USN, for Navy aerospace medical research. Its original purpose was the study of pilot reaction times on transoceanic flights in Navy aircraft. Also Chambers, et al., (3,4) used this task in aviation psychology experiments to measure the effects of sustained acceleration and reduced gravity environments on human performance.

As shown in Figure 1, the device consists of a control unit, a display unit, and a subject response unit. The control unit is a relay switching system capable of presenting eight different sets of 25 pseudo-random stimuli. The unit counts the number of responses and records the time from the first stimulus to the last response over each set



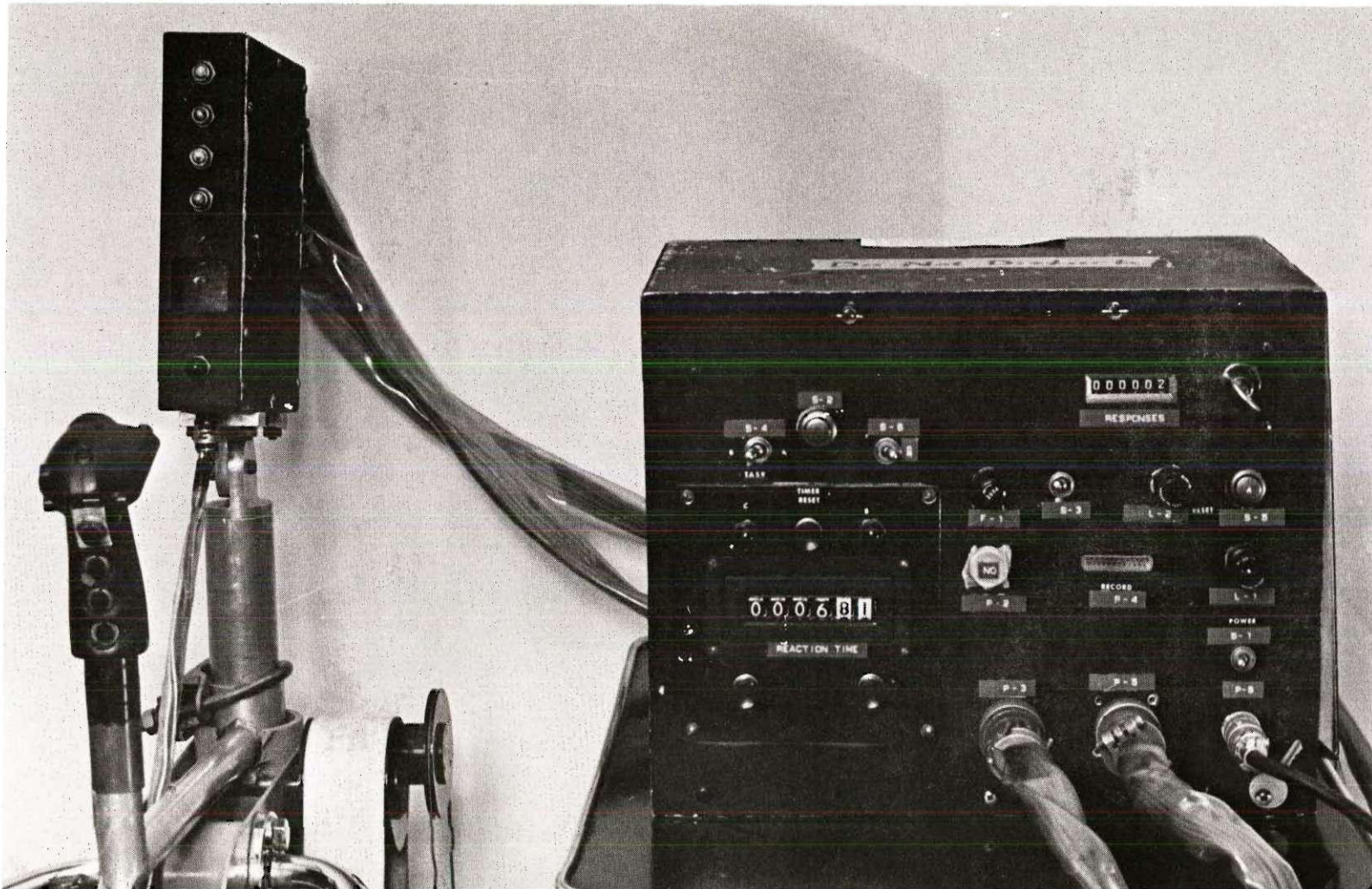


Figure 1. TSCRT Device.



of 25 stimuli.

The display unit consists of a rectangular box with four vertical display lights positioned above a horizontal "nixi-tube" display screen. At each trial, one of the four display lights will be lit with the simultaneous appearance of a four digit number on the display screen. Each digit on the display screen can take on only the values 1, 2, 3, or 4, with each value appearing only once in any given four digit display. The task itself requires the subject to note which of the four display lights is illuminated. The subject then counts from left to right on the display screen in order to read the corresponding ordering digit. This digit indicates the proper response button to be pushed on the subject response unit. For instance, if light 1 was illuminated and the display configuration was "4-1-3-2," the proper response would be pushing the fourth button.

The subject response unit is built into the control handle of a pilot's control stick. It consists of four vertically mounted response buttons in the finger positions. The subject responds by pressing the proper button on the control handle. The response buttons are ordered one through four from the fore-finger position.

#### Bicycle Ergometer

The bicycle ergometer is a Jaquet Universal Ergostat. The ergometer allows loads from 0 to 450 watts in five watt increments through the use of calibrated weights and a

friction drum mechanism. Pedaling speeds of 30, 40, 60, and 90 rpm can be maintained through the use of a synchronizing unit which indicates the subject's deviation from the set pace. Tests were performed seated and subjects were allowed to adjust seat height as desired.

#### Physiological Monitors

A Max Plank respirometer was used. It provides for the collection of a 0.3% or 0.6% sample of the subjects expired air in a rubber bladder for analysis.

A Beckman Oxygen Analyzer, Model D-2, was used to determine the per cent oxygen content of the respiratory gas samples.

#### Cardiotachometer

A Waters Cardiotachometer, Model C-255B, was used to monitor heart rate. Three standard ECG electrodes were used.

#### Subjects

The four subjects for this study were non-pathologic, male, caucasians. Specific subject data is contained in Appendix A.

### Experimental Procedures

#### Training

Each subject underwent a minimum of four training sessions on the TSCRT task. Each training session consisted of three sets of ten trials each. Each trial consisted of

25 stimuli; thus, a total of 750 stimuli were presented in each set and a total of 2250 stimuli in each training session. The task was performed while seated on the bicycle ergometer. A short rest period was provided between each set of trials. The subject was instructed to strive for both accuracy and speed. Subjects were trained to a level estimated to be 120% of the minimum possible response time.

#### Determination of Maximum Aerobic Power

Each subject's maximum aerobic power was determined experimentally on the basis of two submaximal and one super maximal bout on the bicycle ergometer after the method of Astrand (1).

#### Testing Procedures

Subjects arrived at least two hours post-absorptive, dressed in gym shorts and shoes. Two active ECG electrodes were positioned on the fifth intercostal space at the anterior axillary line and an indifferent electrode was placed below the left scapula. All three electrodes were secured with a velcro strap.

The subject mounted the bicycle ergometer (Figure 2) and was given five pre-test trials with the TSCRT task-125 stimuli. Feedback on level of performance was provided during these trials only. Following this the subject was instructed to rest quietly for twelve minutes while two resting gas samples were collected and resting heart rate



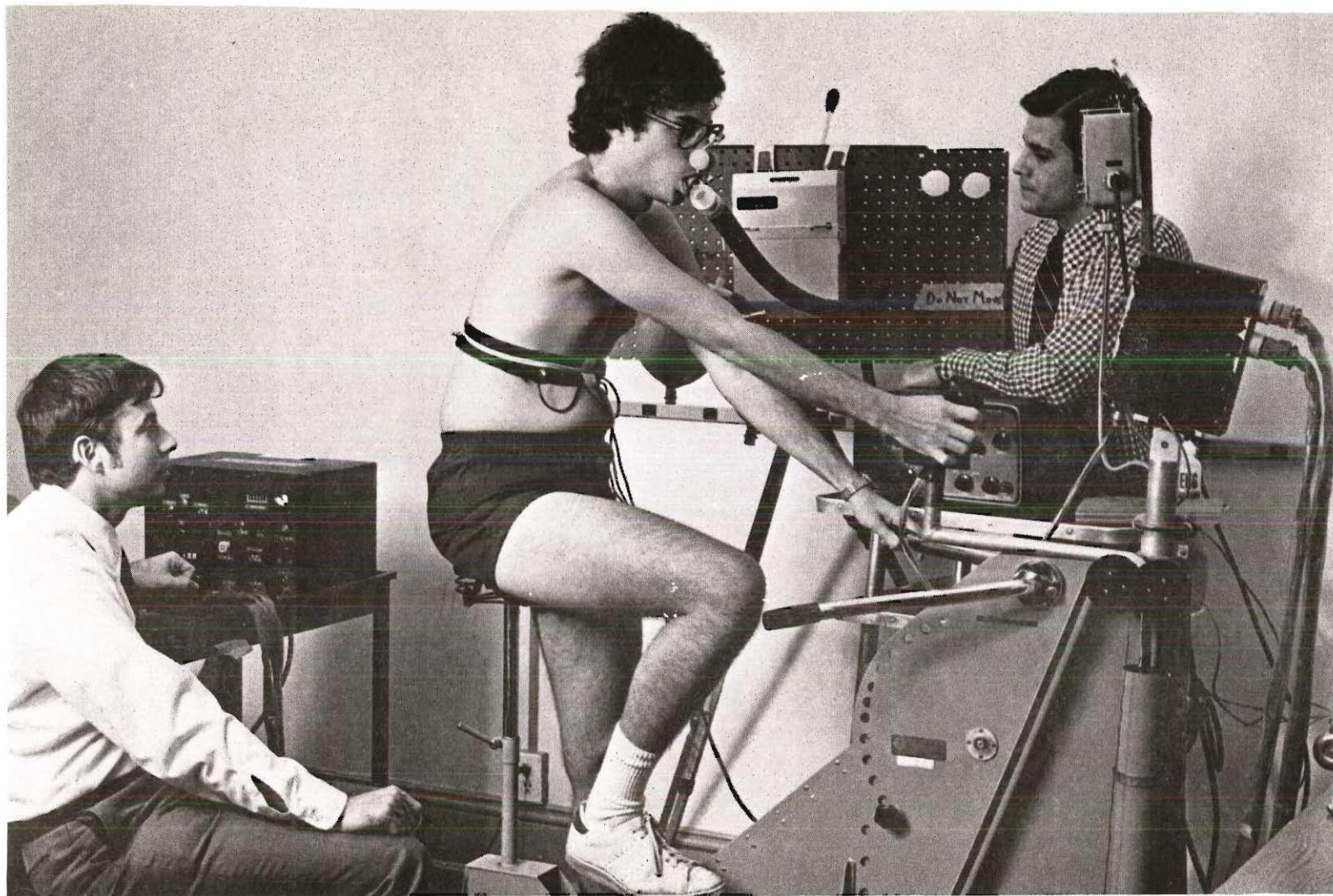


Figure 2. Subject Ready for Exercise.

was recorded.

The subject was instructed to pedal at the set rate and speed for the given duration (Table 1). The TSCRT task was performed immediately upon beginning and each minute thereafter. The experimenter gave a preparatory command followed one to two seconds later by the command "begin" in order to start the subject on each trial of 25 stimuli. Heart rate was recorded prior to beginning each trial. Two steady-state respiratory gas samples were collected during exercise beginning three to five minutes after the start of exercise.

To cease exercise, the command "ready-halt" was given. Immediately, with the cessation of exercise, the subject performed a TSCRT trial. Six recovery period trials were performed at one minute intervals (Figure 3).

Barometric pressure, temperature, and ambient air oxygen concentration, as required for energy expenditure calculations, were measured prior to exercise.

#### Statistical Procedures

Each of the sixteen test conditions were presented to all subjects in a pseudo-random sequence to insure that the data was not confounded by residual learning or day effects (Table 2).

Four subjects at each of sixteen test conditions were considered - a total of 64 tests. The choice reaction time data from each test was divided into five periods - pre-test,

Table 1. Test Condition Duration Times  
(Minutes)

		Rate (rpm)			
		30	40	60	90
Load (Watts)	30	25	25	25	20
	60	20	20	20	15
	120	20	20	20	10
	180	10	15	10	10

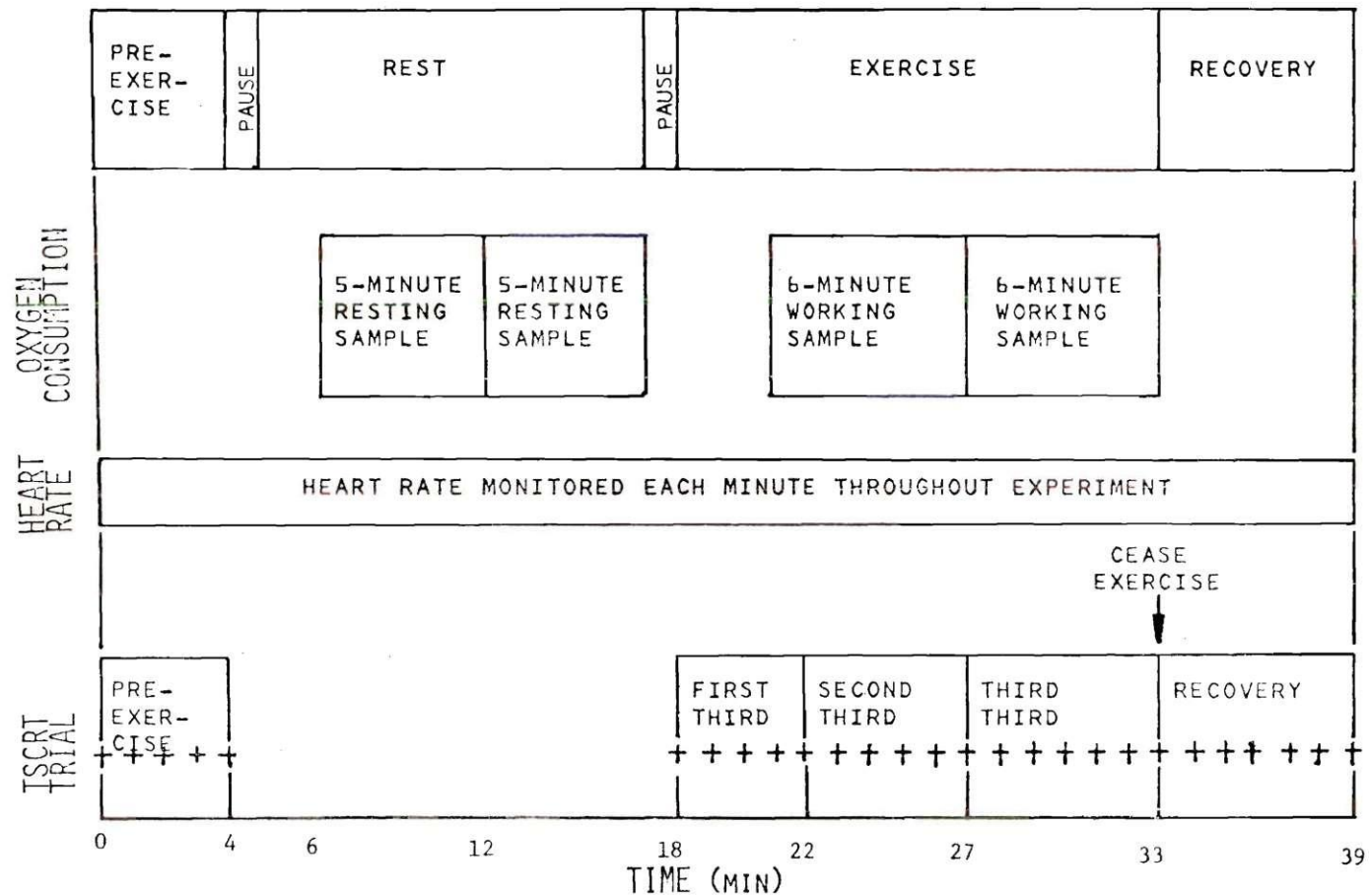


Figure 3. Outline of Typical 15 Minute Test Period.



Table 2. Sequence of Presentation of  
Test Conditions

Subject	Test Condition															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	5	11	14	3	16	8	12	7	2	1	9	13	4	15	6	10
2	14	2	3	9	10	6	1	12	7	13	8	11	15	5	16	4
3	16	10	5	9	1	13	15	6	2	7	3	14	8	4	11	12
4	7	16	5	15	11	1	10	3	14	6	9	2	5	4	13	12



thirds of the exercise period, and recovery. Three observations were chosen at random within each period for a total of fifteen observations per test. This yielded a total of 960 data points for analysis (4 subjects X 16 tests X 15 observations). Data was handled in this way to provide a balanced design and ease of calculation.

The data was analyzed using Analysis of Variance and Analysis of Covariance models. The Biomedical Computer Programs Pack (20) and a Univac 1108 computer were used in the computations.

## CHAPTER IV

### RESULTS

#### Introduction

This chapter presents the data and the statistical analysis of data collected from the four subjects at each of sixteen test conditions - a total of 64 tests. The following models were evaluated:

Mechanical Work Model;

$$RT = u + S_i + L_j + R_k + P_l \text{ (interactions) } + e_{n(ijkl)} \quad (4.1)$$

Energy Expenditure Model;

$$RT = u + S_i + P_l + \text{(interactions)} + a(\dot{V}_{O_2}) + b(\dot{V}_{O_2})^2 \quad (4.2)$$

Heart Rate Model;

$$RT = u + S_i + P_l + \text{(interactions)} + a(HR) + b(HR)^2 \quad (4.3)$$

where, RT = reaction time for 25 stimuli

u = general mean

$S_i$  = subject effect (I = 4)

$L_j$  = load effect (J = 4)

$R_k$  = rate effect ( $k = 4$ )

$P_1$  = period effect ( $L = 5$ )

$a, b$  = regression coefficients

$\dot{V}_{O_2}$  = oxygen consumption rate (l./min.)

HR = heart rate (beats/min.)

$e$  = residual

Subject effects and period effects were evaluated in all models. The difference exists in how the work load is parameterized - either by load and rate or by physiological effects ( $\dot{V}_{O_2}$  and HR). Finally, a model was used to test for residual learning effects.

### Reaction Time Models

#### Mechanical Model

The data was initially subjected to an analysis of variance using a model of the form (4.1) to test subject, work, rate, and period effects on choice reaction time. Subject, work, and period effects were found significant at the 1% level. Subject-work, subject-rate, work-rate, and subject-period interactions were found significant at the 1% level. The least squares estimates and corresponding significance tests for the first order terms and second order interaction terms are presented in Tables 3-5 and Figure 4. A complete ANOVA table is presented in Appendix B.

Table 3. ANOVA Model of Reaction Time as a Function of Subject, Work, Rate, and Period

Model:  $RT = u + S_i + L_j + R_k + P_j + (\text{interactions}) + e_n(ijkl)$

General Mean  $u = 24.316$

Subject Effect

$S_1 = 1.227$   $S_2 = -2.612$   $S_3 = 4.830$   $S_4 = -3.445$   
 $F(3,640) = 1113.82$  Significant at 1% level

Work Effect

$L_1 = -0.434$   $L_2 = 0.389$   $L_3 = 0.331$   $L_4 = -0.286$   
 $F(3,640) = 13.61$  Significant at 1% level

Rate Effect

$R_1 = 0.043$   $R_2 = 0.196$   $R_3 = -0.089$   $R_4 = -0.050$   
 $F(3,640) = 1.81$

Period Effect

$P_1 = 0.082$   $P_2 = 0.505$   $P_3 = 0.108$   $P_4 = -0.122$   $P_5 = -0.573$   
 $F(4,640) = 9.49$  Significant at 1% level

Subject-Work Effect

		Work (Watts)			
		30	60	120	180
Subject	1	0.030	-1.267	1.186	0.051
	2	0.688	0.716	-1.113	-0.291
	3	-0.190	-0.307	0.370	0.127
	4	-0.528	0.858	-0.443	0.113
		$F(9,640) = 14.57$ Significant at 1% level			

Table 4. ANOVA Model of Reaction Time as a Function of Subject, Work, Rate, and Period

Subject-Rate Effect

	Rate (rpm)			
	30	40	60	90
Subject 1	0.637	0.580	-1.033	-0.184
2	-1.049	-0.425	1.625	-0.151
3	1.248	-0.797	0.500	-0.951
4	-0.836	0.642	-1.092	1.286

$F(9,640) = 27.93$  Significant at 1% level

Work-Rate Effect

	Rate (rpm)			
	30	40	60	90
Work (Watts) 30	-1.238	-0.063	0.984	0.317
60	-0.631	-0.051	-0.169	0.851
120	1.228	0.388	-0.470	-1.146
180	0.641	-0.274	-0.345	-0.022

$F(9,640) = 16.11$  Significant at 1% level

Subject-Period Effect

	Period				
	1	2	3	4	5
Subject 1	-0.064	-0.162	-0.105	-0.023	0.354
2	-0.363	0.053	0.068	-0.121	0.363
3	0.395	0.442	0.104	0.015	-0.956
4	0.032	-0.333	-0.069	0.129	0.239

$F(12,640) = 2.46$  Significant at 1% level

Table 5. ANOVA Model of Reaction Time as a Function of Subject, Work, Rate, and Period

Work-Period Effect

		Period				
		1	2	3	4	5
Work (Watts)	30	0.117	-0.390	-0.140	0.067	0.346
	60	0.256	0.173	-0.187	-0.369	0.127
	120	-0.218	-0.037	0.174	0.136	-0.055
	180	-0.155	0.254	0.153	0.166	-0.418
		<hr/>				
		$F(12,640) = 1.29$				

Rate-Period Effect

		Period				
		1	2	3	4	5
Rate	30	-0.282	-0.178	0.157	0.192	0.111
	40	-0.056	-0.166	0.059	-0.261	0.424
	60	0.435	-0.016	0.109	-0.163	-0.365
	90	-0.097	0.360	-0.325	0.232	-0.170
		<hr/>				
		$F(12,640) = 1.48$				

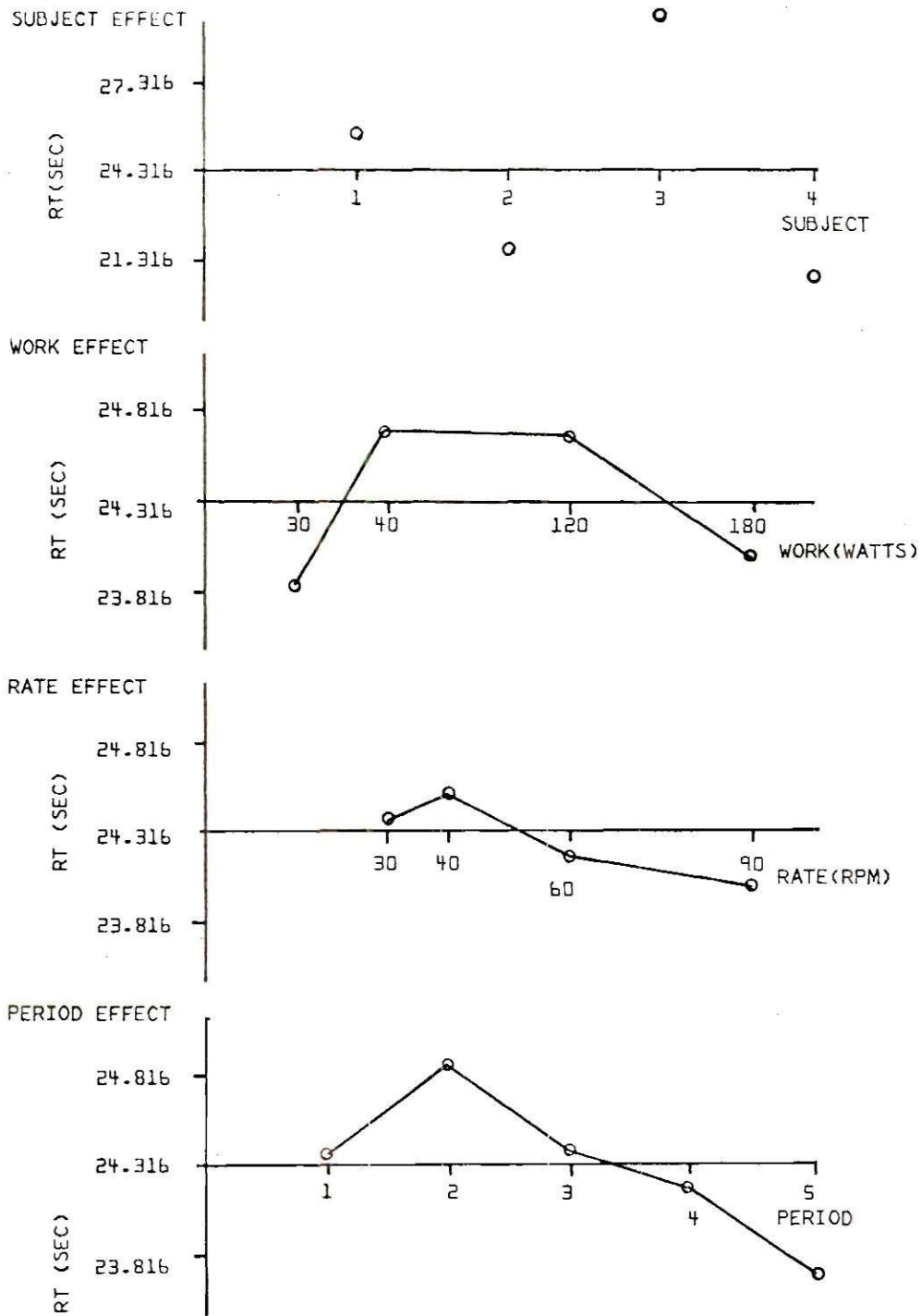


Figure 4. The Effect of Subject, Work, Rate, and Period on Choice Reaction Time.



### Energy Expenditure Model

A covariance model of the form (4.2) was formulated and a general linear hypothesis technique was used to test for significant subject and period effects as well as oxygen consumption rate effects. Subject and period effects were shown to be significant at the 1% level. Linear and second order polynomial regression terms were also shown to be significant. The results of this test are summarized in Table 6 and Figure 5.

### Heart Rate Model

A covariance model of the form (4.3) was formulated and a general linear hypothesis technique was used to test for significance of subject, period, and heart rate effects. A significant subject and period effect was detected at the 1% level. A second order polynomial regression on heart rate was shown to be significant. The results of this test are tabulated in Table 7 and Figure 6.

### Error Rate Models

Models similar in form to (4.1) were formulated with number of errors replacing reaction time as the dependent variable. The effect of subject, work, rate, and period effects on number of errors was investigated. No highly significant terms were detected; however, Figure 7 gives some insight into trends in the number of errors for each



Table 6. Energy Expenditure Covariance Model

Model:  $RT = u + S_i + P_1 + (\text{interactions}) + a(\dot{V}_{O_2}) + b(\dot{V}_{O_2})^2$

General Mean:  $u = 19.711$

Subject Effect

$S_1 = 1.161$     $S_2 = -2.554$     $S_3 = 4.762$     $S_3 = -3.369$   
 $F(3,938) = 364.71$    Significant at 1% level

Period Effect

$P_1 = 0.082$     $P_2 = 0.506$     $P_3 = 0.107$     $P_4 = -0.122$     $P_5 = -0.573$   
 $F(4,938) = 3.31$    Significant at 1% level

Subject-Period Effect

		Period				
		1	2	3	4	5
Subject	1	-0.064	-0.162	-0.105	-0.023	0.354
	2	-0.363	0.053	0.068	-0.121	0.363
	3	0.395	0.442	0.104	0.015	-0.956
	4	0.032	-0.333	-0.067	0.129	0.239
		$F(12,938) = 0.856$				

Physiological Effect -  $\dot{V}_{O_2}$

$F(1,938) = 43.37$  for  $H_0: a = 0$ ; significant at 1% level

$F(2,938) = 21.84$  for  $H_0: a = 0, b = 0$ ; significant at 1% level

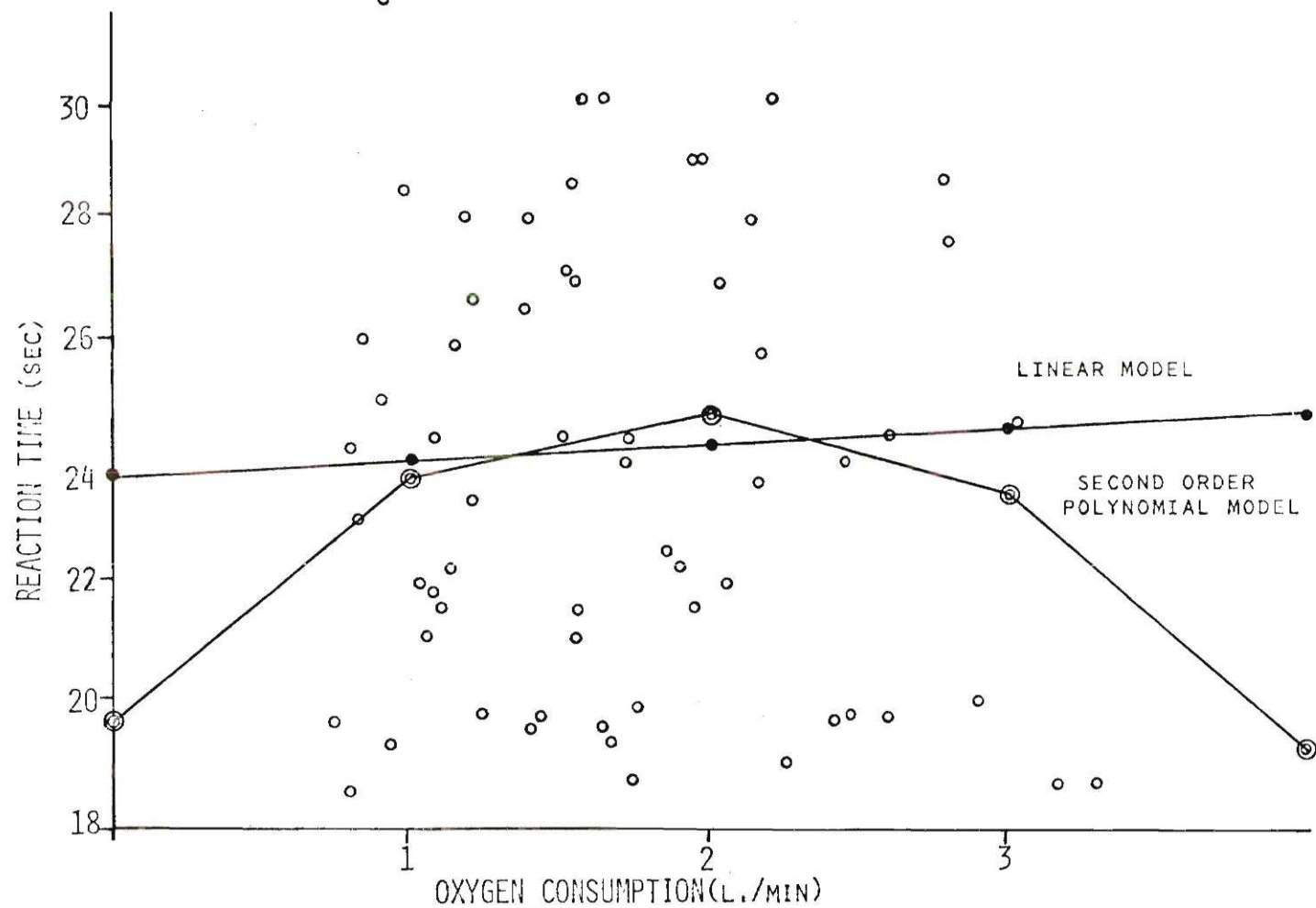


Figure 5. Choice Reaction Time as a Function of Oxygen Consumption.

Table 7. Heart Rate Covariance Model

Model:  $RT = u + S_i + P_l + (\text{interactions}) + a(\text{HR}) + b(\text{HR})^2$

General Mean:  $u = 20.488$

Subject Effect

$S_1 = 1.310 \quad S_2 = -2.671 \quad S_3 = 4.735 \quad S_4 = 3.374$   
 $F(3, 938) = 354.91$  Significant at 1% level

Period Effect

$P_1 = 0.720 \quad P_2 = 0.385 \quad P_3 = -0.196 \quad P_4 = -0.462 \quad P_5 = -0.457$   
 $F(4, 938) = 4.221$  Significant at 1% level

Subject-Period Effect

	Period				
	1	2	3	4	5
1	0.038	-0.222	-0.152	-0.075	0.411
2	-0.388	0.022	0.455	-0.089	0.000
3	0.199	0.530	0.214	0.084	-1.027
4	0.151	-0.330	-0.089	0.080	0.616

$F(12, 938) = 0.936$

Physiological Effect - HR

$F(2, 938) = 4.963$  for  $H_0: a=0, b=0$ ; significant at 1% level

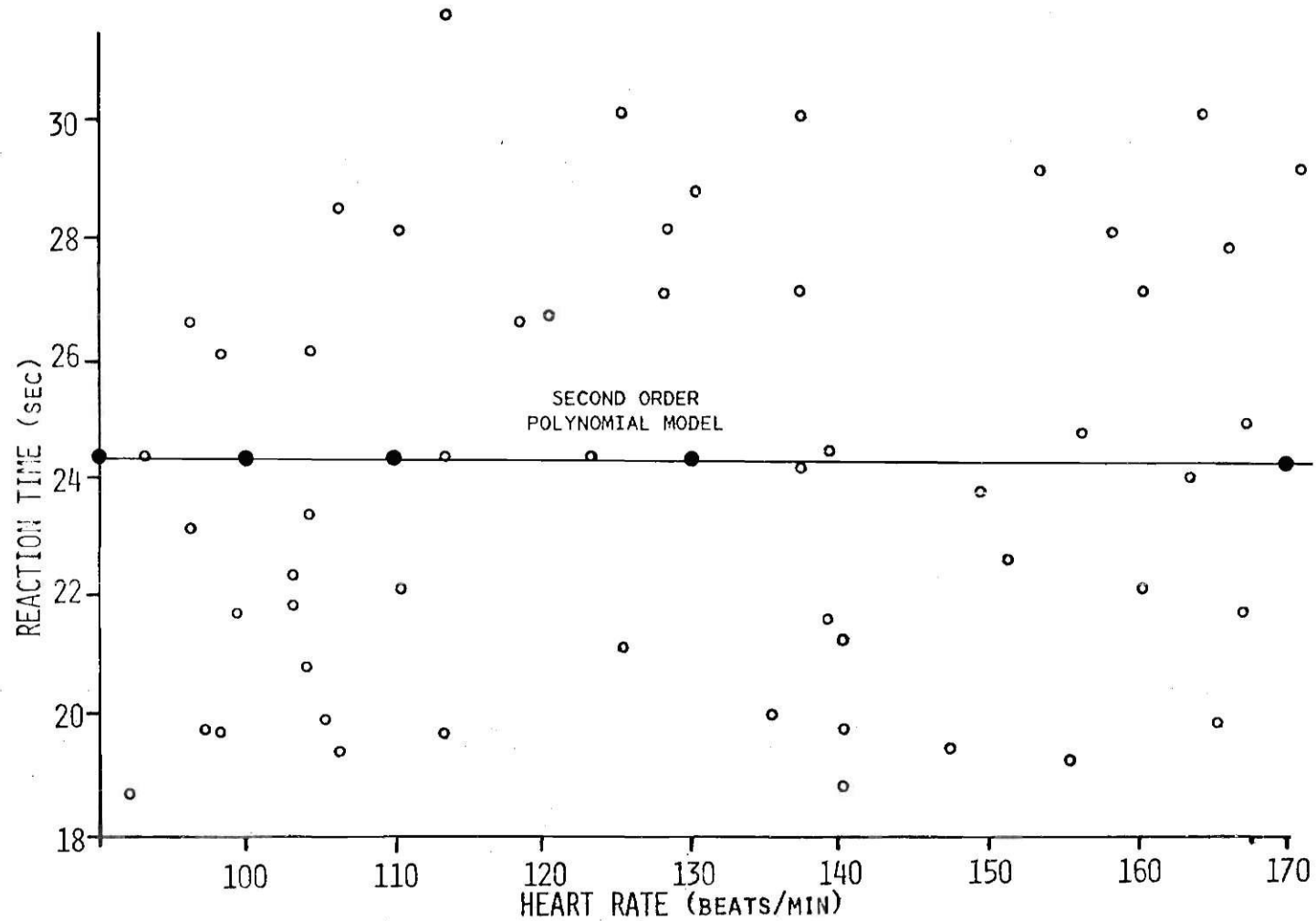


Figure 6. Choice Reaction Time as a Function of Heart Rate.

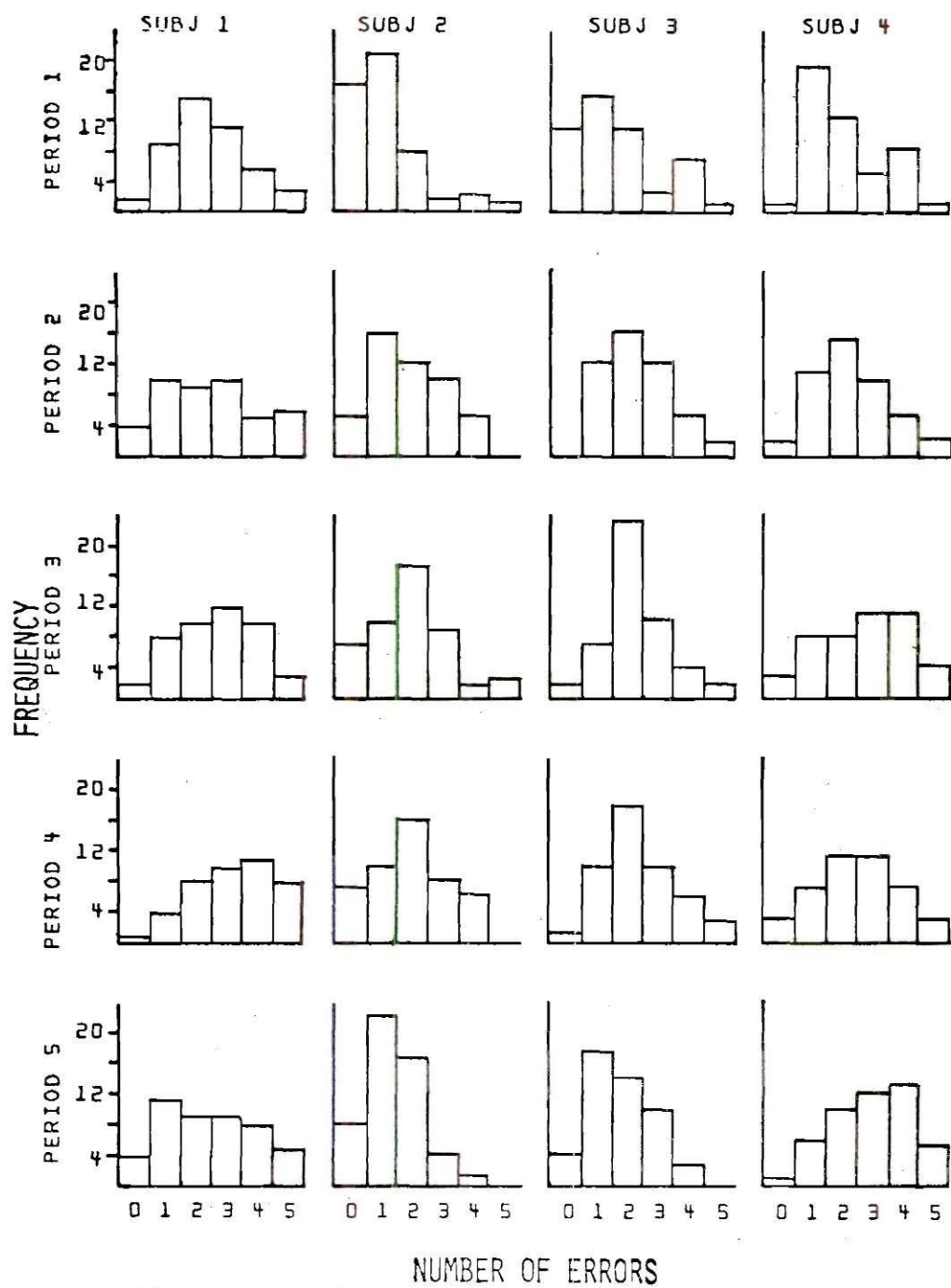


Figure 7. Subject and Period Effects on Error Rate.



subject in each period. The complete ANOVA analysis is presented in Appendix C.

#### Tests for Significant Residual Learning Effects

Although subjects underwent extensive training sessions and test conditions were randomly presented to all subjects in order to block out learning and day effects, a possible decrease in reaction time over the experiment was observed (Figure 8). A covariance model was formulated to test for the significance of residual learning effects. Residual learning was shown to have no significant effect on reaction time. The results of this test are tabulated in Appendix D.

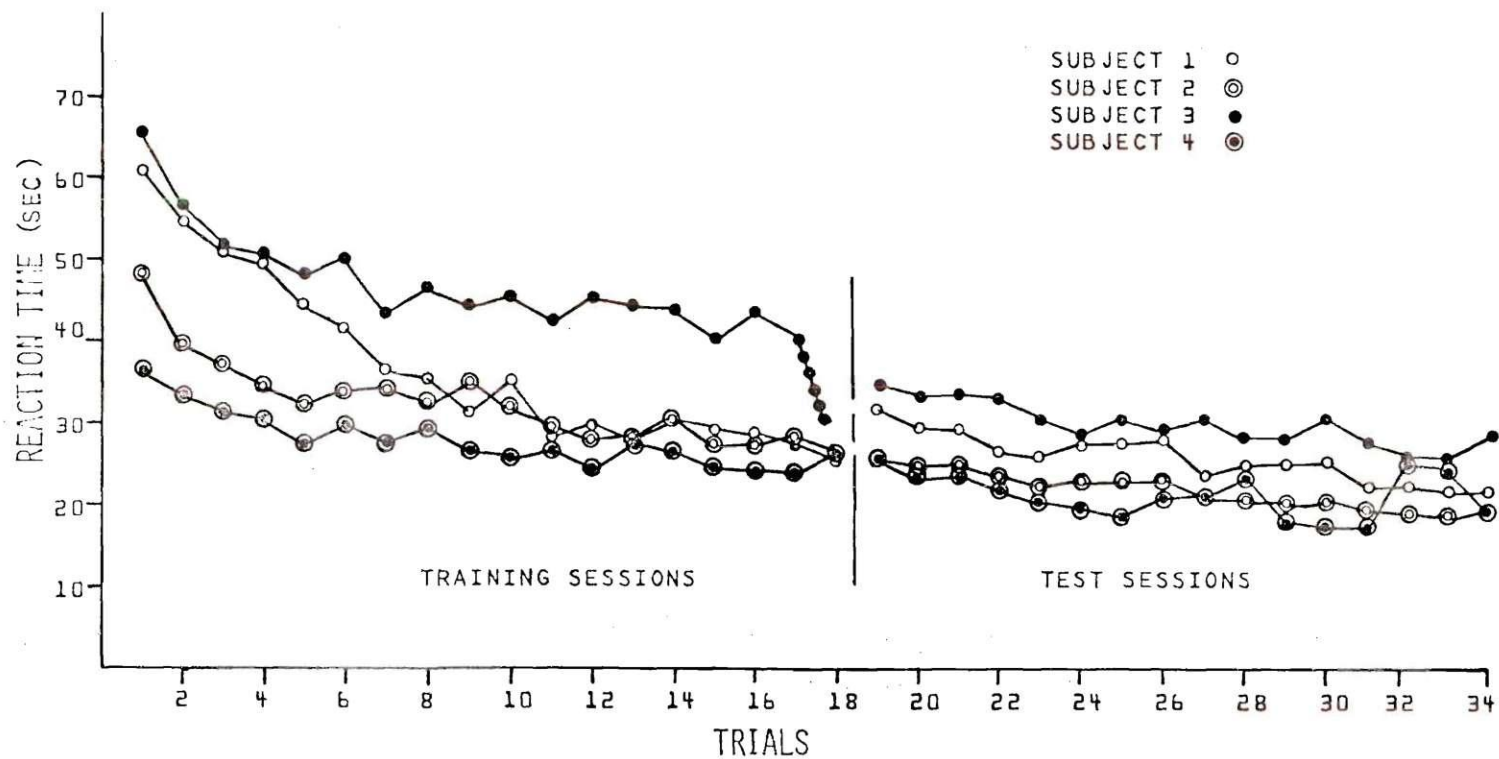


Figure 8. Subject Learning Curves.

## CHAPTER V

### DISCUSSION

This chapter discusses the experimental results presented in Chapter IV.

#### Reaction Time Models

Although a very significant subject effect was detected at the 1% level in all models, equations (4.1), (4.2), and (4.3), a definitive explanation could not be postulated beyond pure subject variability. As Appendix A indicates, the subjects did not vary significantly in somatotype. There were age differences and differences in level of fitness as indicated by maximum aerobic power; however, it is not possible to argue that those differences effected choice reaction time since no trend is apparent.

A significant work effect was found at the 1% level. It is felt that the range of work loads investigated covers those conditions which might reasonably be encountered in industry. At loads below 30 watts, pedal force becomes so low that subjects find it extremely difficult to maintain the required pedaling rate and/or keep their feet on the pedals. At loads much above 180 watts, the motor task becomes extremely difficult to maintain for any reasonable period of time. The models showed that reaction time was

significantly faster at the light and heavy loads of 30 and 180 watts as compared to the intermediate loads of 60 and 120 watts. It is felt that this is of practical significance; however, for bicycle ergometer work, the mechanism by which work stress effects choice reaction time is not clearly understood.

The rate effect was not shown to be statistically significant, although a trend showing reaction time to decrease with speed of pedaling was detected. Subjects quickly developed a rhythm of pedaling and were able to maintain the required rate to within 5% except in those tests conditions where pedal force was extremely low (90 rpm, 30 watts) or extremely high (30 rpm, 180 watts). In all test conditions except those stated above, it is believed that the rate effect quickly became absorbed in the overall work effect with the subjects' achievement of pedaling rhythm.

A significant period effect was detected at the 1% level. The results indicate that whole-body exercise initially impaired performance; however, as the subject established a work rhythm and adjusted to the work stress in the second and third periods of exercise, choice reaction time actually dropped to a level below the mean. A significant improvement was seen with recovery.

The results are considered of practical importance. In work situations where individuals may be called upon to perform a skilled psychomotor task at a high level of

performance while simultaneously performing whole-body exercise, an attempt should be made to design the job in such a way as to insure adjustment to the work stress before starting the task. This conclusion corresponds favorably with the intuitive decision of many working people who find that they perform better and their work is easier, if they maintain a rhythm in their job. Further, the results indicate that whether the work continues for a significant period after the achievement of this steady-state exercise or ceases and recovery is allowed, the individual's performance can be expected to show substantial improvement as compared to his average choice reaction time.

Subject-work, subject-rate, work-rate, and subject-period interactions were shown to be significant at the 1% level. Since the subject effect cannot be traced to any particular differences among the subjects, it is difficult to make statements about the interaction of this effect with mechanical and time effects. However, the significance of these effects does indicate the validity of the variables chosen to investigate, since work, rate, period, and the work-rate interaction significantly effected subject TSCRT performance. Plots of the work-rate interaction as well as all other two-way interactions indicated no trends. Consequently, an operational explanation for these interactions is not offered.

Covariance models formulated with subject, period, and



heart rate effects showed a significant second order polynomial regression on heart rate at the 1% level. Because of the large number of degrees of freedom, the test was very powerful and showed statistical significances even though the actual trend in the data was negligible (see Figure 6). Thus, although the model is significant, it is not representative of the data; and thus, it cannot be used as a means of predicting performance level.

Models formulated as above with the substitution of oxygen consumption rate for heart rate yielded significant linear and second order polynomial regression terms on oxygen consumption; however, for the same reasons as stated above, these models are considered non-representative and non-predictive (see Figure 5).

#### Error Rate Models

Statistical significance was observed for many of the variables considered but viable explanations or interpretations could not be conjectured. It is concluded that any effects other than what is shown in Figure 7 are pure random variations. The figure does indicate that all subjects experienced an increase in variance with period. Also, a shift in the distribution mode was seen, in that the mode of the distribution increased with the start of exercise and through the exercise periods, but decreased to near the pre-test value with recovery.

### Residual Learning

The test for residual learning indicated no significant residual learning effect. The degree and rate of learning appeared to be significantly effected by the development of technique in each individual. Those individuals who were able to reduce the decision time required for each response to a near reflex level while concentrating on the motor response experienced the greatest learning.

## CHAPTER VI

### CONCLUSIONS AND RECOMMENDATIONS

Since neither the TSCRT task nor the bicycle ergometer exercise are tasks of high face validity, that is, there are very few, if any, industrial or military situations in which an individual would be faced with similar exercise and psychomotor tasks, it is not possible to draw direct conclusions about the effects of whole-body exercise on any particular class of industrial or military tasks. However, the results do indicate clearly, that an individual's choice reaction time is significantly effected by work stress. Although this effect cannot be directly related to any particular individual trait at present, it bears consideration when assigning individuals to work situations in which they might be called upon to perform a skilled psychomotor task while undergoing whole-body exercise.

A significant work effect and a significant trend in the rate effect were observed; however, no viable explanation or interpretation could be conjectured. It is believed that the rate effect may have possibly become absorbed in an overall work effect with the establishment of rhythm in pedaling.

The significant trend toward improved task performance

with exercise and then again with recovery is of particular interest. Since this is the only study known to the experimenter which measures performance of a skilled task during whole-body exercise, the result of increases in measured performance with subject adjustment to the work stress is completely new.

Further, this study, which investigates a wider range of work loads and work rates than any previous study found, indicates an increase in recovery performance as measured by choice reaction time. Previous studies of recovery performance of skilled psychomotor tasks indicate either no change or a decrease in performance during recovery.

Finally, for practical purposes, the effect of both physiological parameters monitored on choice reaction time is negligible in that the models formulated could in no way represent the large variance observed in both heart rate and oxygen consumption rate data. On the basis of the findings here it is felt that heart rate and oxygen consumption rates can be discounted as having any effect on choice reaction time within the range of conditions investigated.

The results found here definitely indicate possibilities for further research. A study with a larger number of subjects might uncover the source of subject differences. Further, male-female and age differences could be investigated. The development of a psychomotor task of high face validity which could be performed while exercising on one

of the several types of ergometers presently available would be of great value. In general, a larger body of literature, investigating performance on many tasks at many work loads and rates is necessary. From such a body of literature, conclusions might be drawn which could lead to the formulation of predictive statements about the exact mechanism causing performance changes under work stress and the statements about the direction and degree of such changes under particular work conditions.



APPENDIX A  
SUBJECT DATA

Table 8. Subject Data.

Subject	Age	Height	Weight	Resting HR (b./min)	Maximum V <sub>O<sub>2</sub></sub> (l./min)
1	23	6'-0"	165	60	3.6
2	29	5'-10"	176	70	3.4
3	34	5'-11"	165	95	3.4
4	21	6'-0"	175	50	3.8

## APPENDIX B

ANOVA ANALYSIS FOR MODEL OF REACTION TIME  
AS A FUNCTION OF SUBJECT, WORK, RATE, AND PERIOD

Table 9. ANOVA Table for Model of Reaction Time as Function of Subject, Work, Rate, and Period

Source of Variation	Degrees of Freedom	F	
Mean	1	181577.45	
Subject (S)	3	1113.82	**
Work (W)	3	13.61	**
Rate (R)	3	1.81	
Period (P)	4	9.49	**
SW	9	14.57	**
SR	9	27.93	**
WR	9	16.11	**
SP	12	2.46	**
WP	12	1.29	
RP	12	1.48	
SWR	27	46.66	**
SWP	36	1.99	**
SRP	36	1.29	
WRP	36	1.42	*
SWRP	108	1.30	
Residual	640		

General Mean = 24.32

\*\* = Significant at 1% level

\* = Significant at 5% level

## APPENDIX C

ANOVA ANALYSIS FOR MODEL OF ERROR RATE  
AS A FUNCTION OF SUBJECT WORK, RATE, AND PERIOD





APPENDIX D  
COVARIANCE TEST FOR  
SIGNIFICANCE OF LEARNING EFFECTS

Table 11. Covariance Analysis for Residual Learning

$$\text{Model: } RT = u + S_i + T_j + P_l + (\text{interactions}) + a(L)$$

where: RT = reaction time for 25 trials  
 u = general mean  
 $S_i$  = subject effect ( $I = 4$ )  
 $T_j$  = test condition effect ( $J = 16$ )  
 $P_l$  = period effect ( $L = 5$ )  
 a = regression coefficient  
 L = learning coefficient

and

L = 1 for subject's 1st four trials  
 L = 2 for subject's 2nd four trials,  
 etc.

ANOVA Table:

Source of Variation		Degrees of Freedom	F
Subject	(S)	3	712.69 **
Test Condition	(T)	15	6.74 **
Period	(P)	4	9.95 **
ST		45	9.37 **
SP		12	2.37 **
TP		60	1.37
STP		180	1.45 **
Residual		639	

Regression Coefficient:

$$a = -2.230; F(1, 639) = 2.124, \text{ not significant}$$

\*\* = significant at 1% level

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